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[54] **ARCING FAULT DETECTOR TESTING AND DEMONSTRATION SYSTEM**

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[51] **Int. Cl.**[6] **H02B 1/04**

[52] **U.S. Cl.** **324/424**; 324/536; 324/423

[58] **Field of Search** 361/42; 324/424, 324/418, 509, 423, 536

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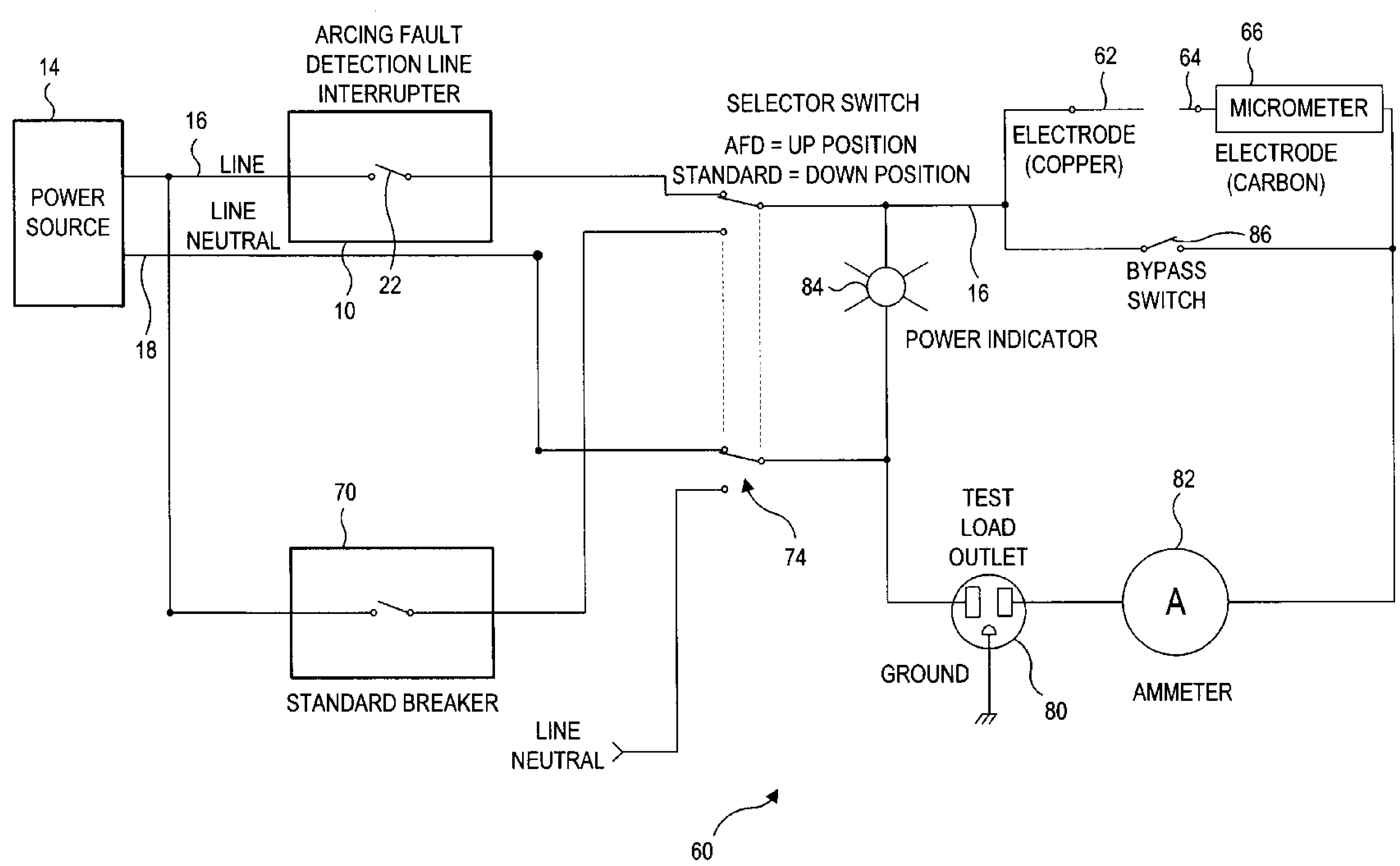
[57] **ABSTRACT**

An apparatus for demonstrating and testing the operation of an arcing fault detector. The apparatus comprises an electrical circuit including line and neutral conductors connected between a power source and a load. A selector switch is movable between a first position and a second position in order to selectively route load current across either an arcing fault detector or standard circuit breaker. A pair of electrodes is positioned between said selector switch and the load for producing an arcing condition on the line conductor. The arcing fault detector preferably comprises a sensor for monitoring the rate of change of electrical current on the line conductor and producing a rate-of-change signal, a means for producing a pulse each time the rate-of-change signal exceeds a selected threshold, a means for filtering the rate-of-change signal and/or pulse to eliminate signals or pulses representing changes in electrical current outside a selected frequency range, a means for producing a count signal representing a number of unfiltered pulses occurring within a selected time interval, and a means for generating a trip signal in response to the count signal exceeding a trip threshold level indicative of an arcing fault condition.

23 Claims, 9 Drawing Sheets



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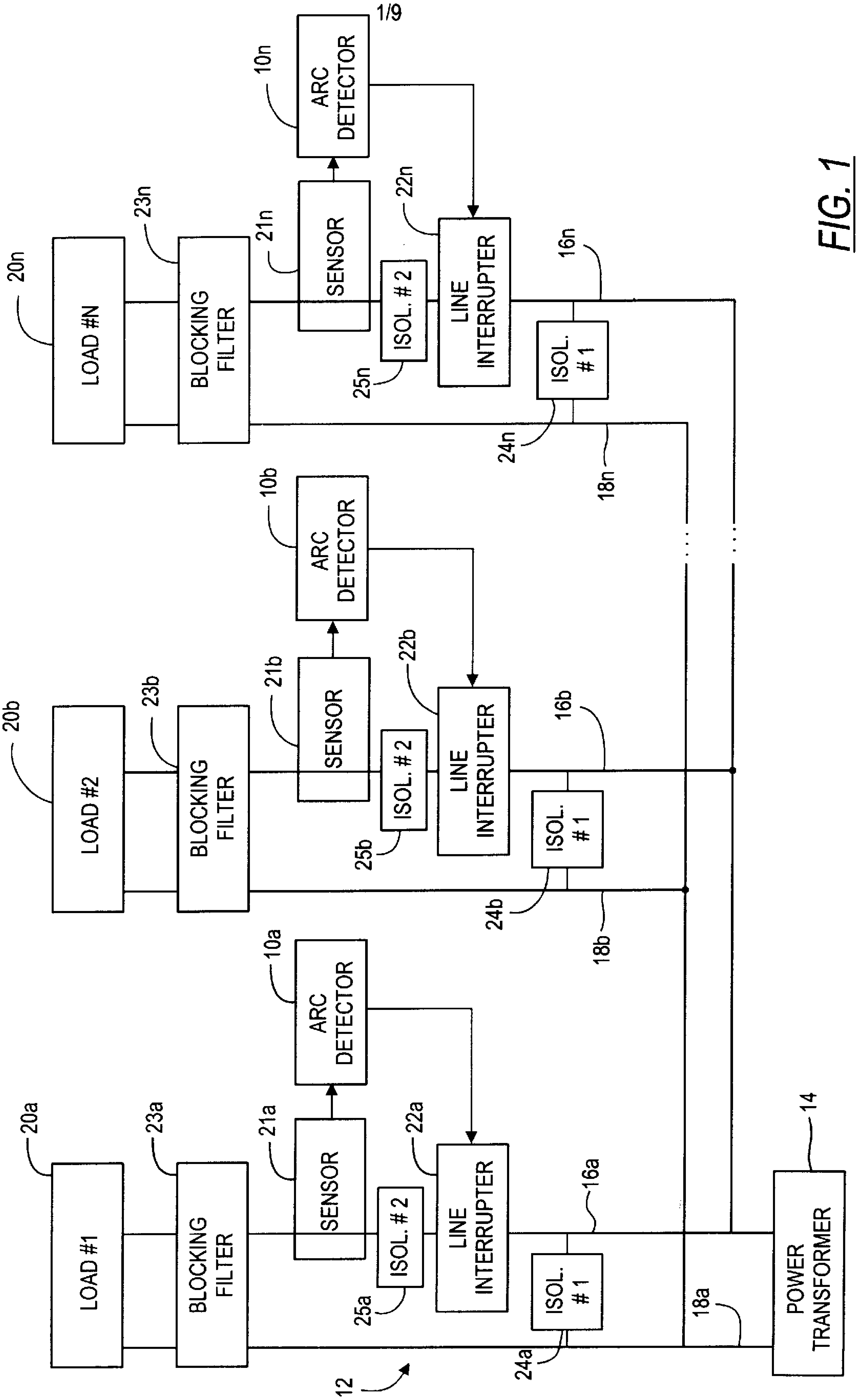
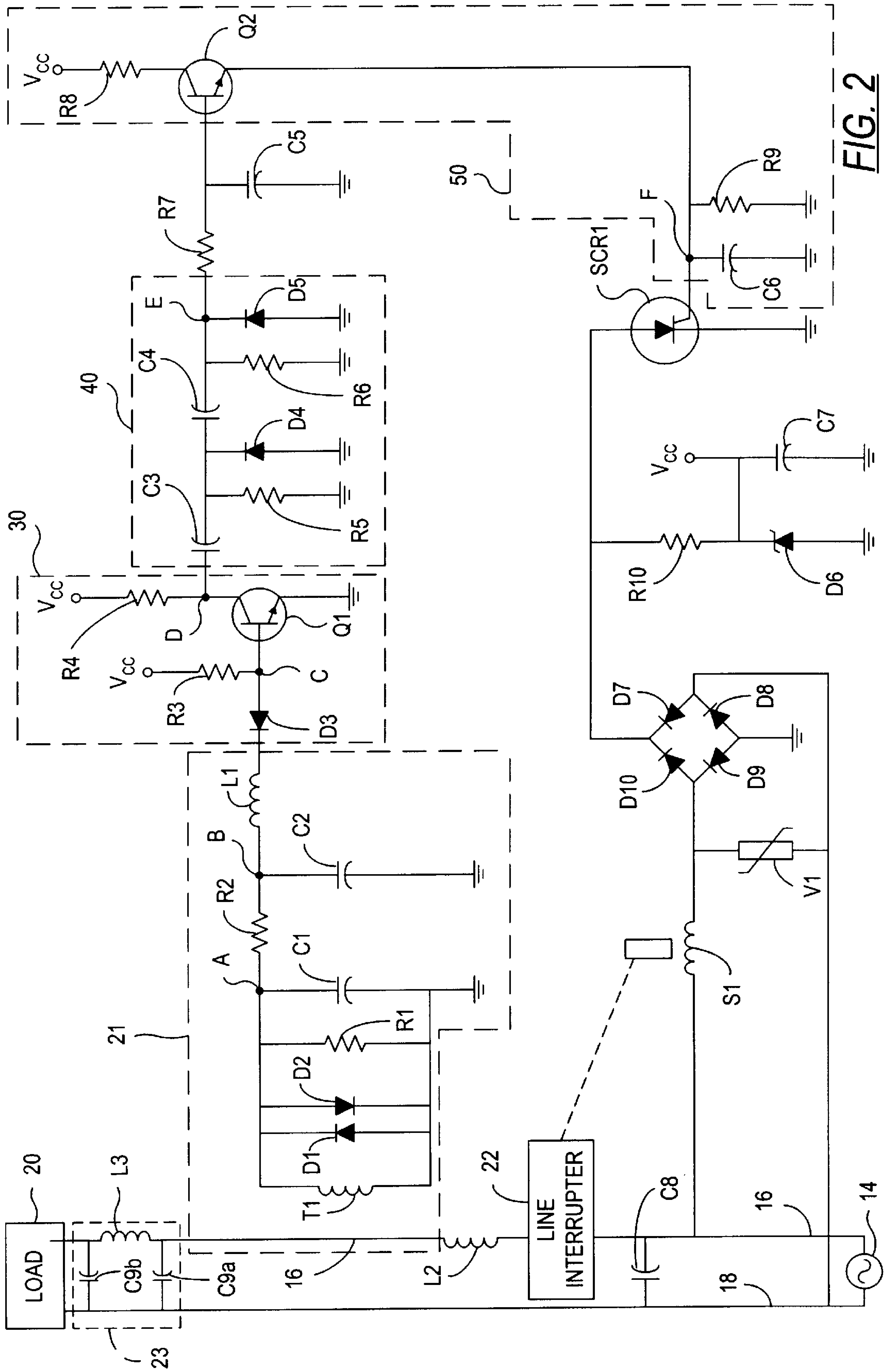

1/9
ARC DETECTOR
10n
SENSOR
21n
LINE INTERRUPTER
22n
BLOCKING FILTER
23n
LOAD #N
20n
ISOL. # 2
25n
ISOL. # 1
24n
16n
18n
ARC DETECTOR
10b
SENSOR
21b
LINE INTERRUPTER
22b
BLOCKING FILTER
23b
LOAD #2
20b
ISOL. # 2
25b
ISOL. # 1
24b
16b
18b
ARC DETECTOR
10a
SENSOR
21a
LINE INTERRUPTER
22a
BLOCKING FILTER
23a
LOAD #1
20a
ISOL. # 2
25a
ISOL. # 1
24a
16a
18a
POWER TRANSFORMER
14
12

FIG. 1



VCC
R8
Q2
C5
R7
50
F
R9
C6
SCR1
E
D5
C4
40
R6
D4
C3
R5
30
R4
D
Q1
R3
C
D3
VCC
C7
R10
D6
D7
D8
D10
D9
L1
B
C2
R2
A
C1
V1
S1
21
R1
D2
D1
T1
22
LINE INTERRUPTER
20
LOAD
L3
C9b
C9a
16
L2
C8
18
14
23

FIG. 2

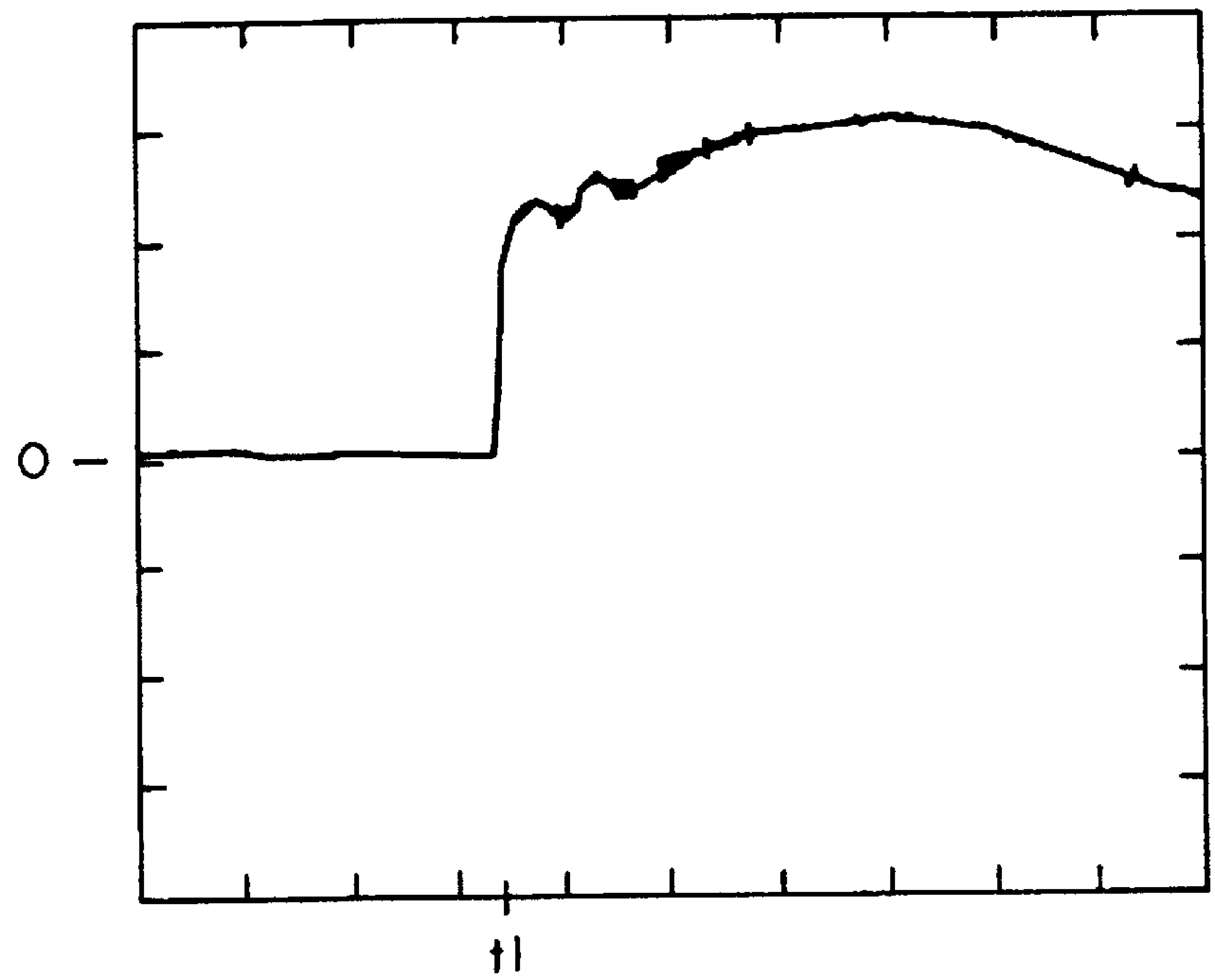


FIG. 3a

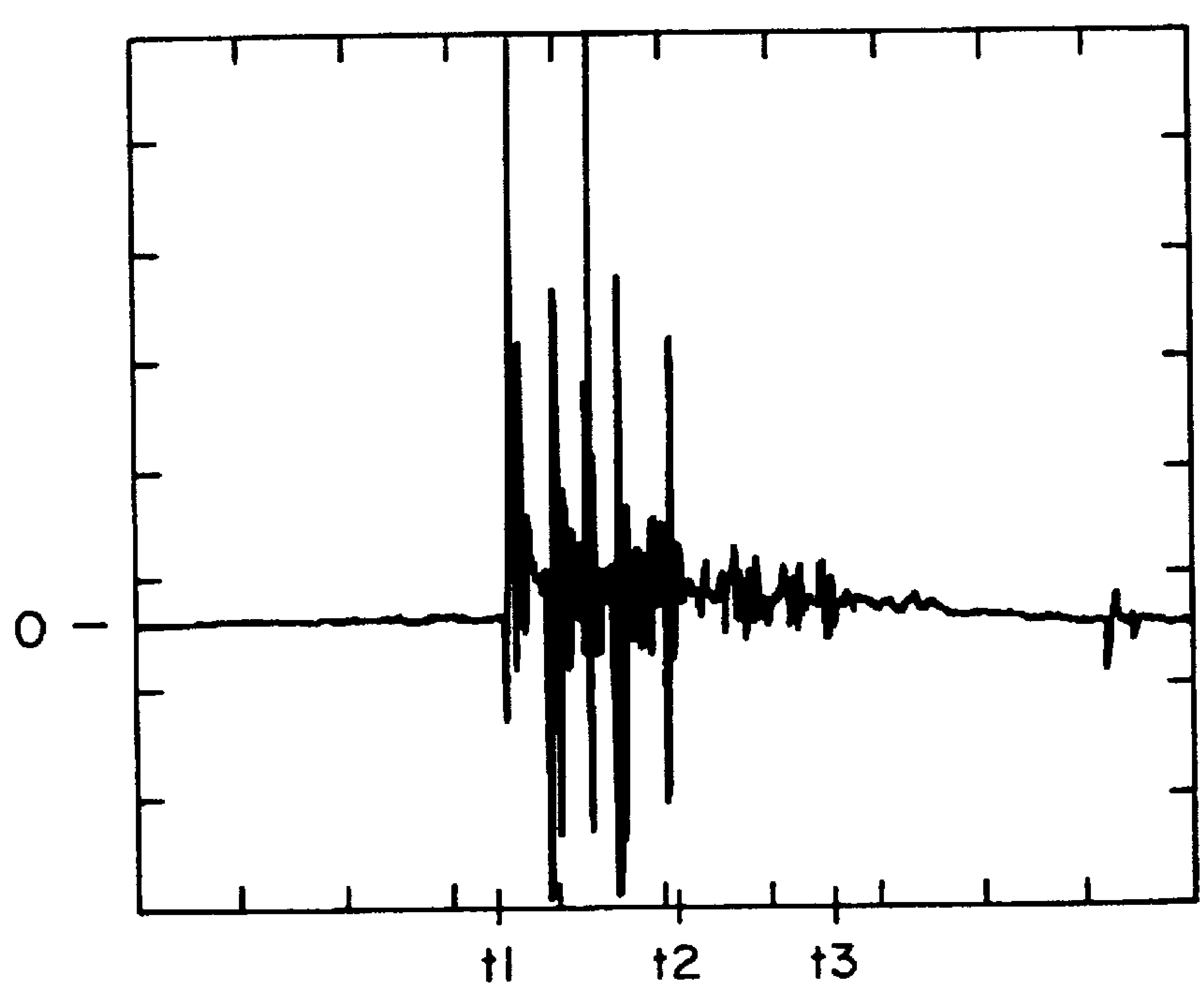


FIG. 3b

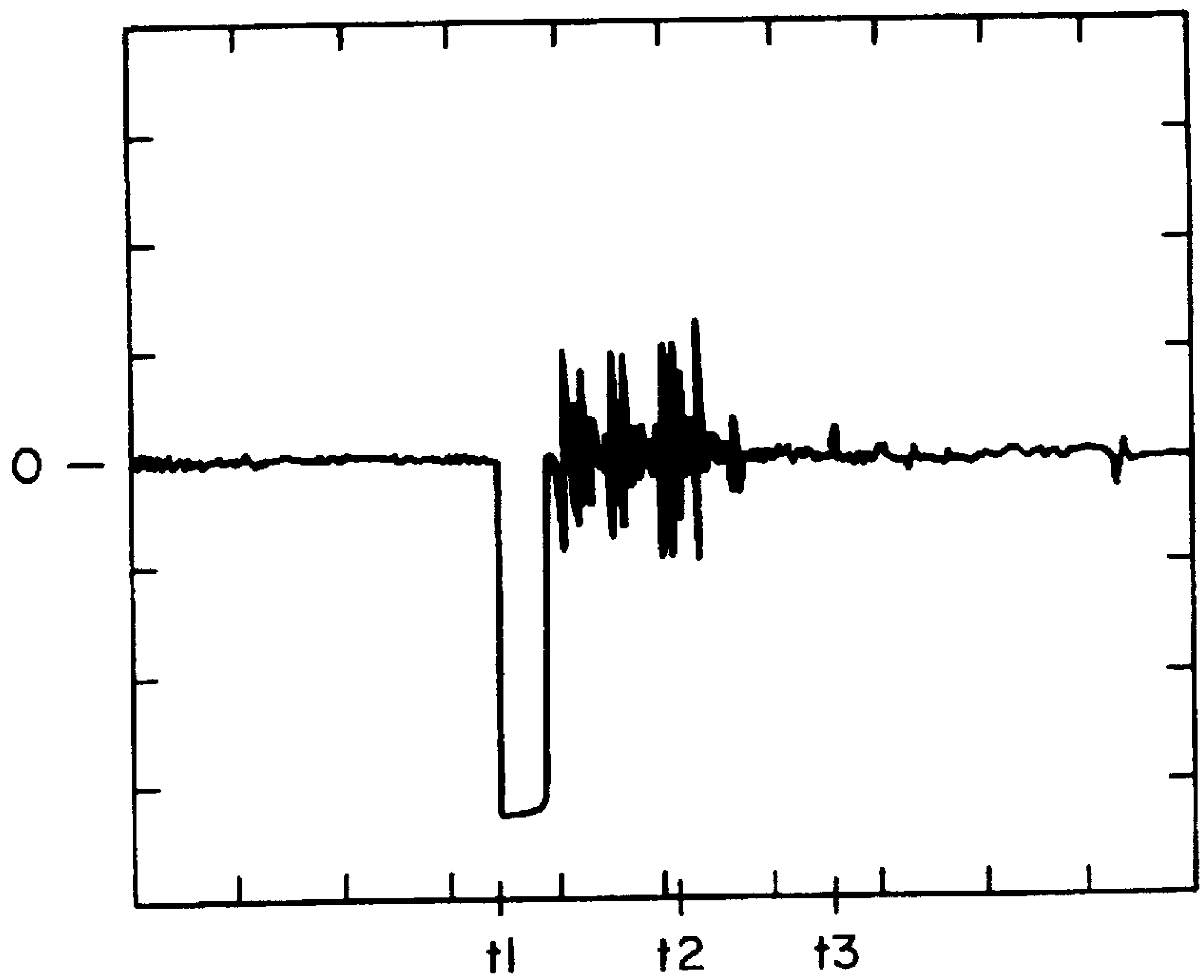


FIG. 3c

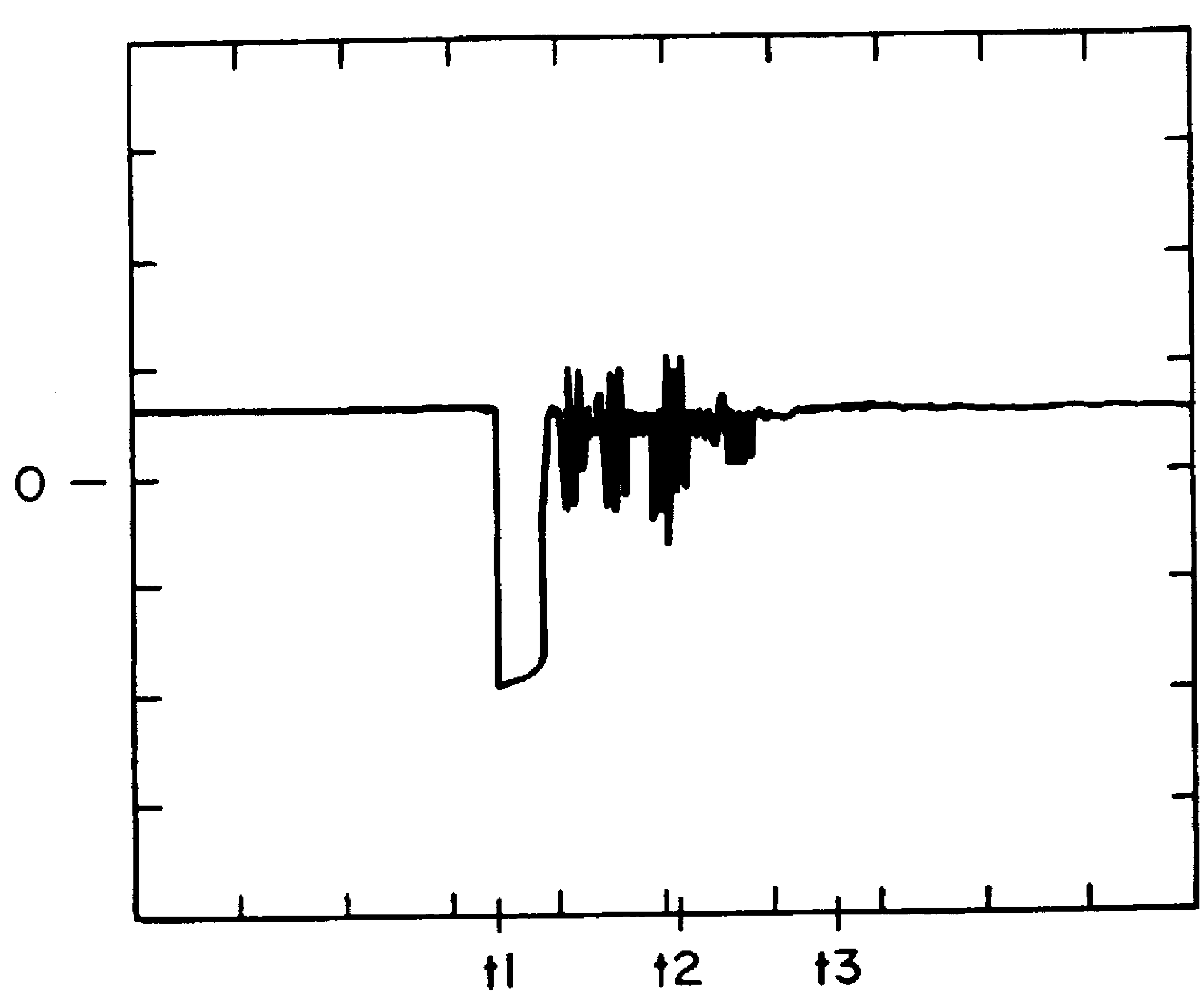


FIG. 3d

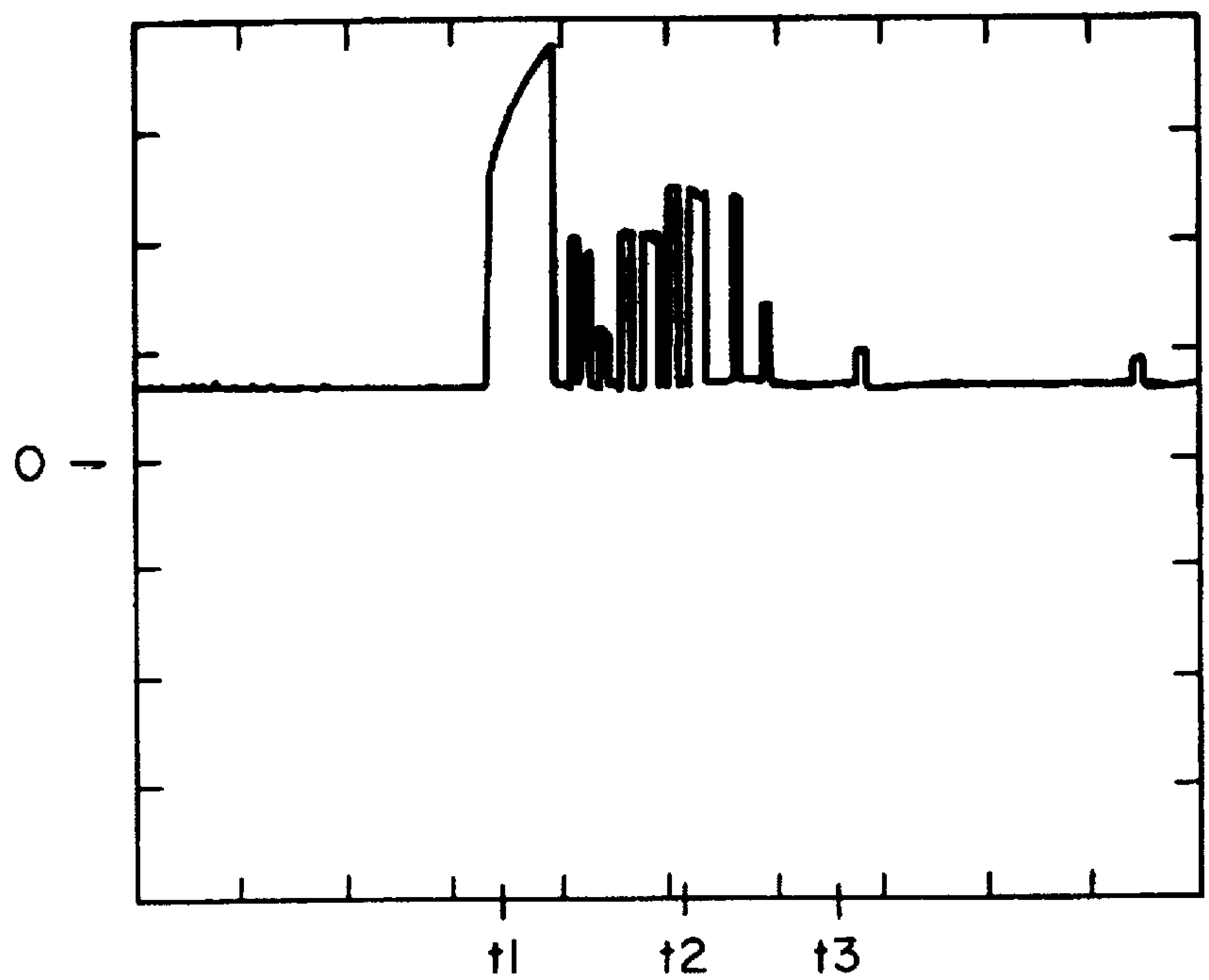


FIG. 3e

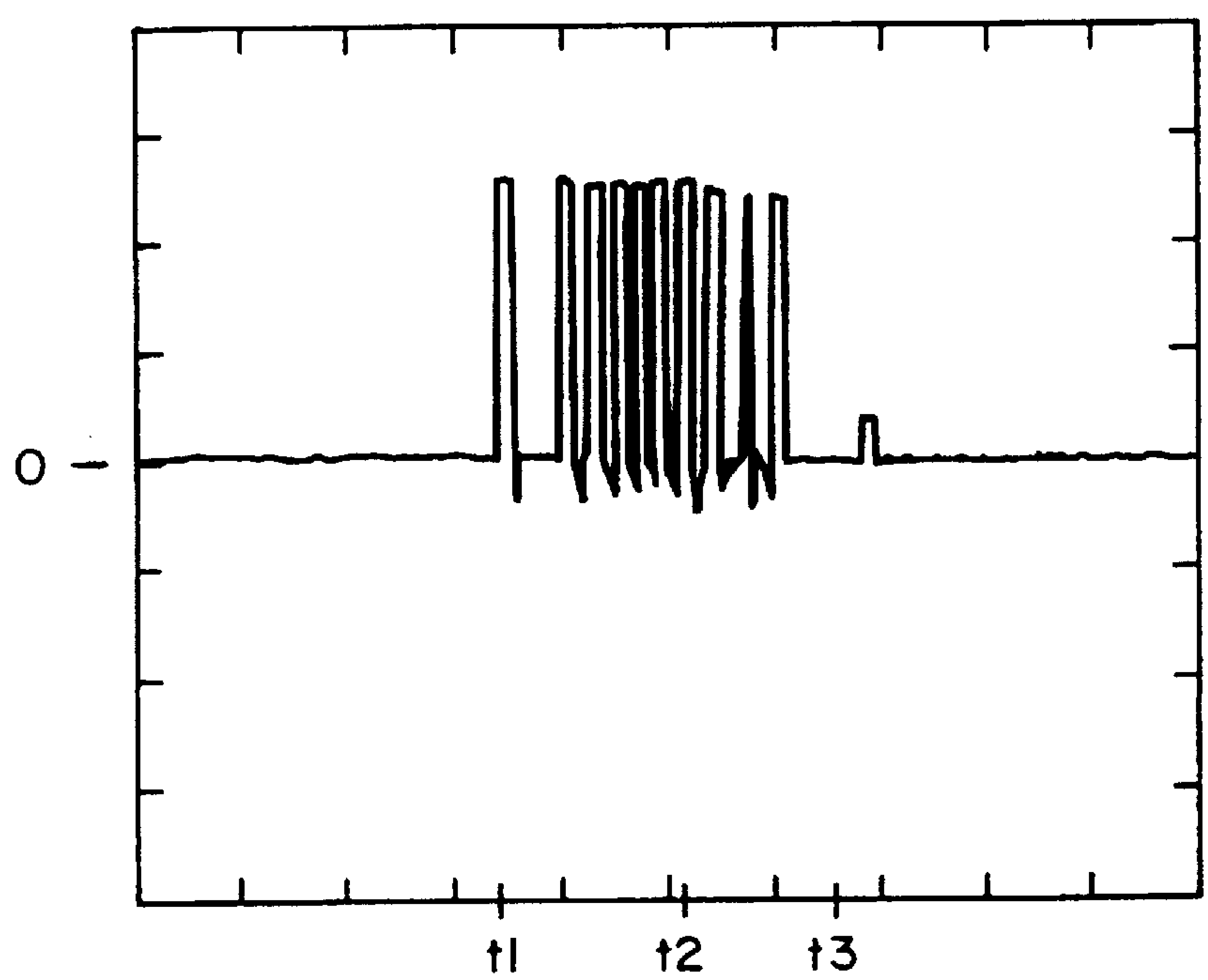


FIG. 3f

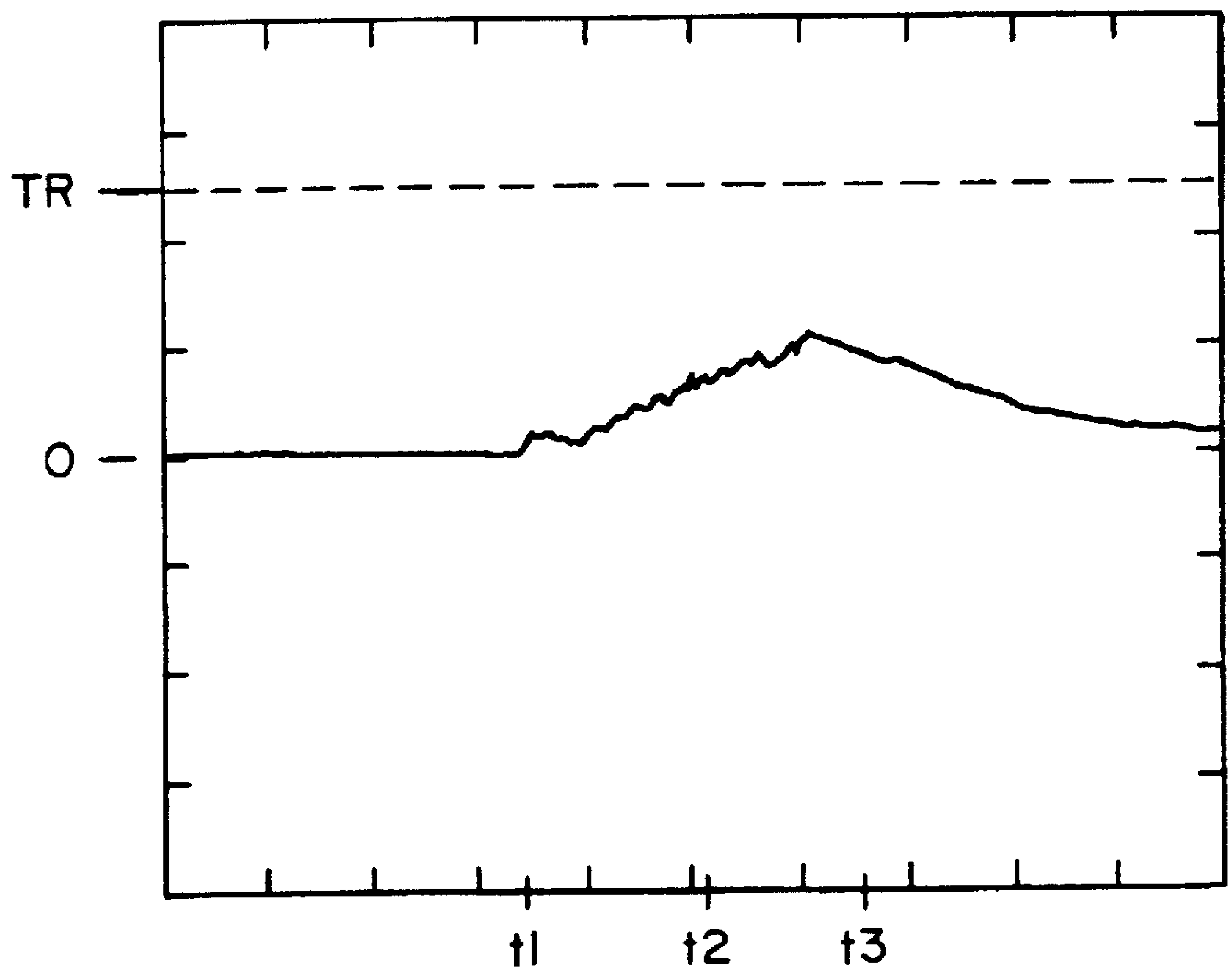


FIG. 3g

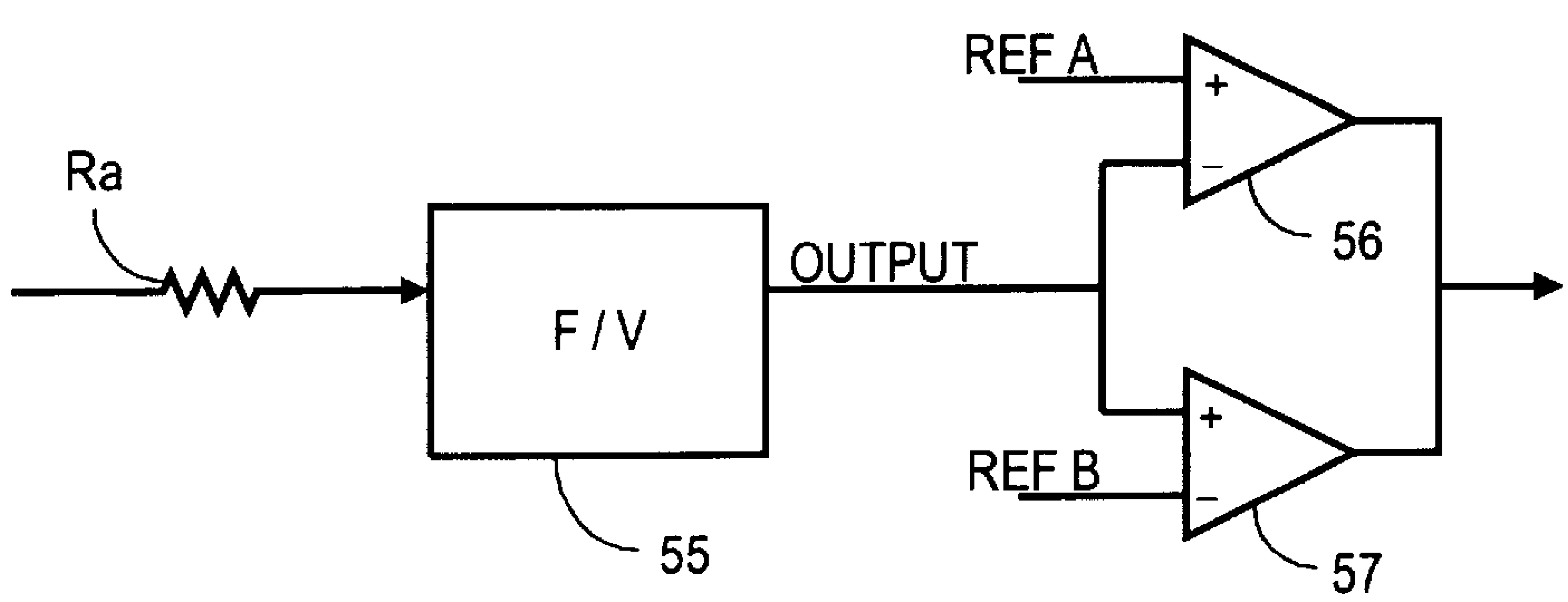
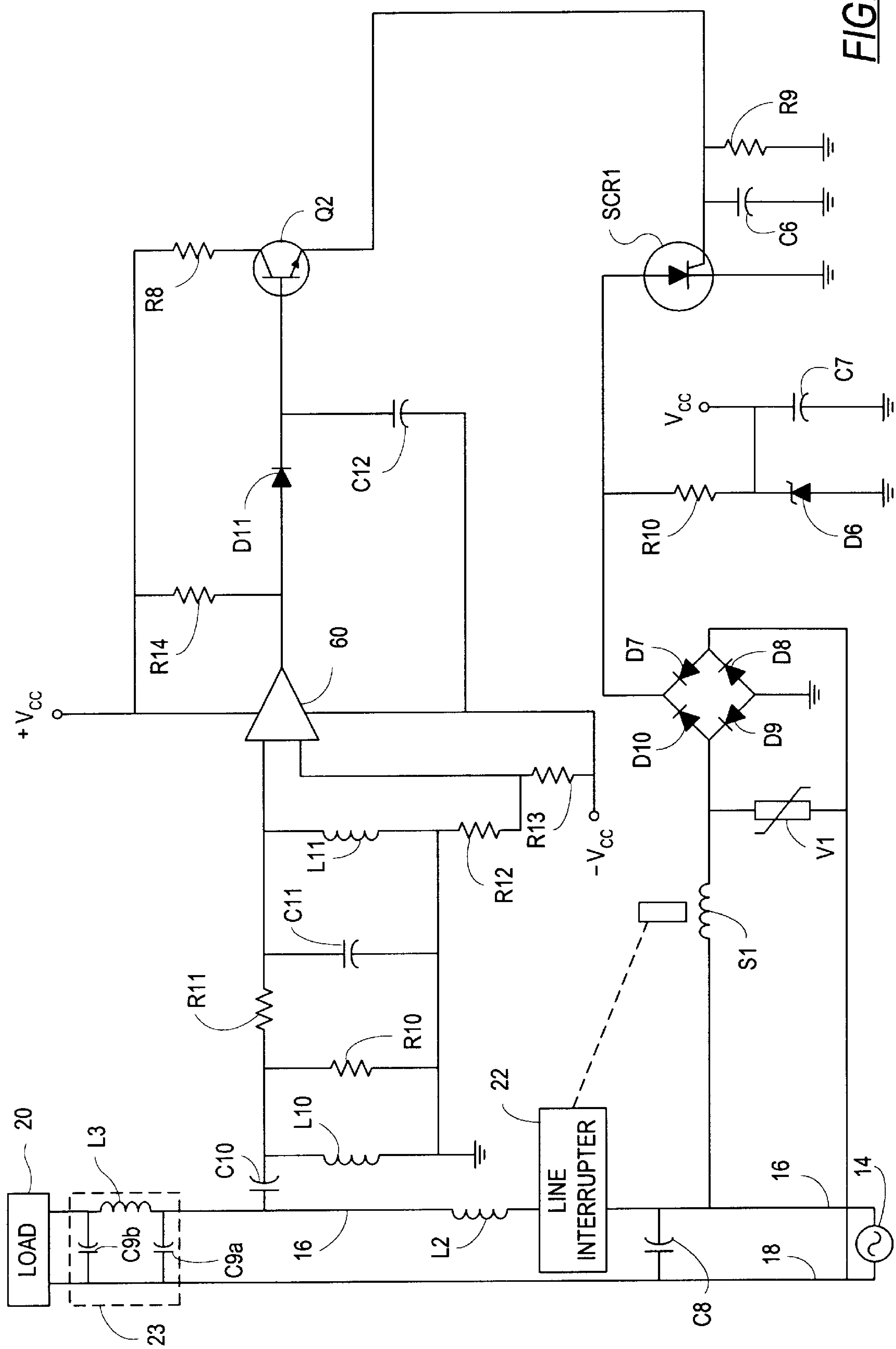


FIG. 4


+Vcc
R8
Q2
R14
D11
C12
60
SCR1
R9
C6
C7
Vcc
R10
D6
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D8
D9
D10
V1
S1
-Vcc
R13
R12
L11
C11
R11
R10
L10
C10
22
LINE INTERRUPTER
L2
16
C8
18
14
20
LOAD
L3
C9b
C9a
23

FIG. 5

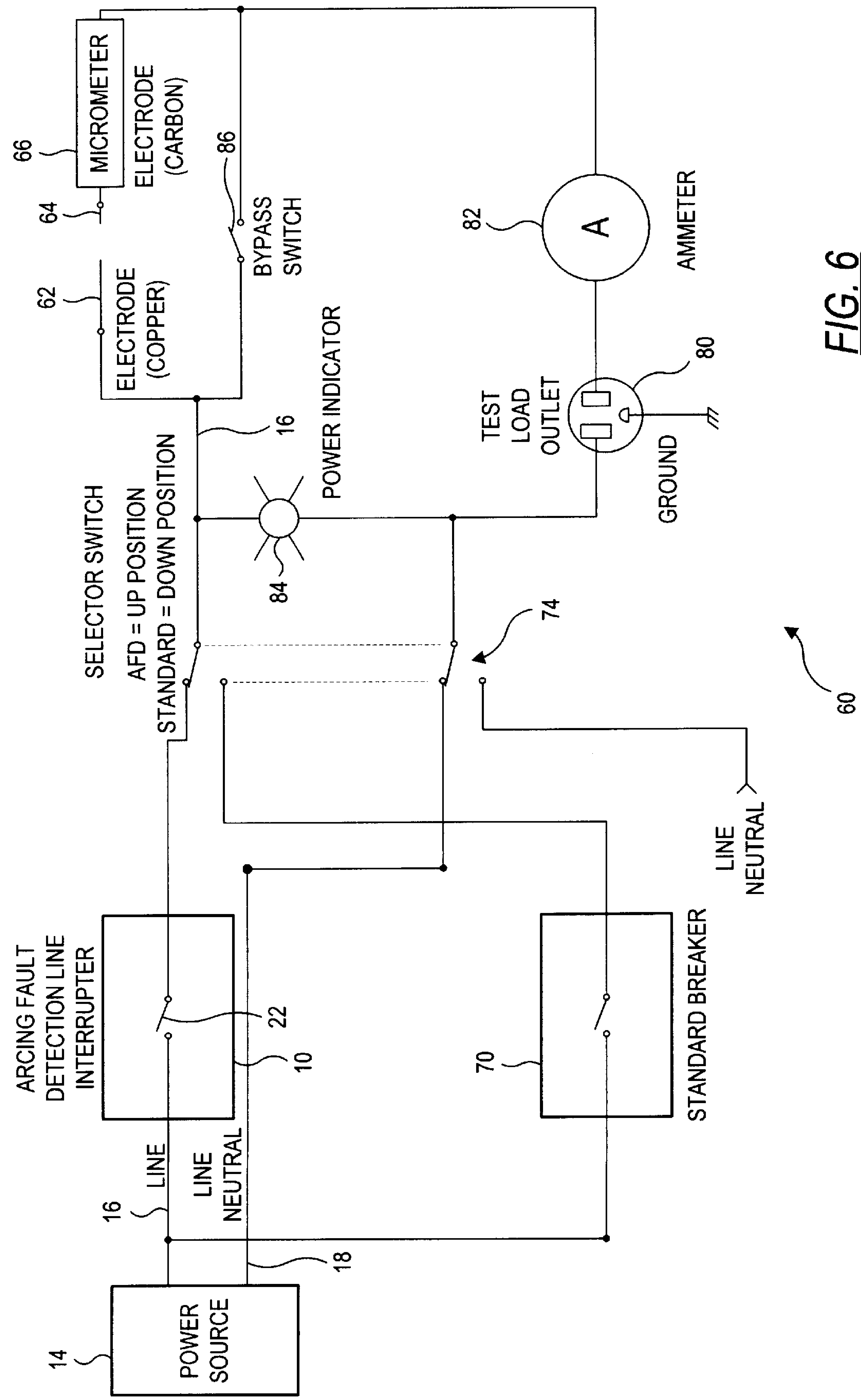
MICROMETER
ELECTRODE (CARBON)
ELECTRODE (COPPER)
BYPASS SWITCH
AMMETER
A
TEST LOAD OUTLET
GROUND
POWER INDICATOR
SELECTOR SWITCH
AFD = UP POSITION
STANDARD = DOWN POSITION
LINE NEUTRAL
ARCING FAULT DETECTION LINE INTERRUPTER
STANDARD BREAKER
LINE
LINE NEUTRAL
POWER SOURCE
66
64
62
86
82
80
16
84
74
60
22
10
70
16
18
14

FIG. 6

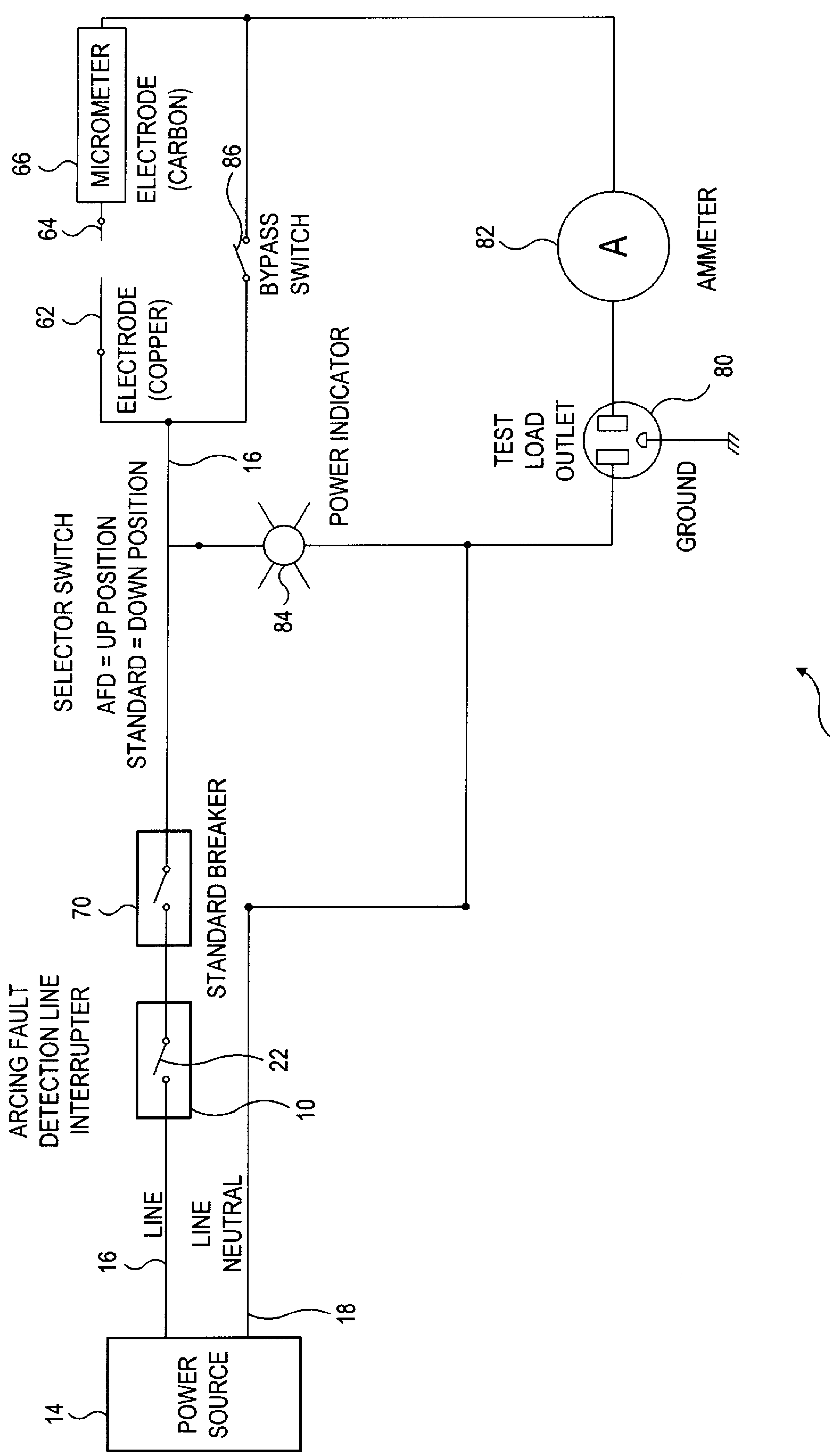
MICROMETER
66
64
ELECTRODE (CARBON)
62
ELECTRODE (COPPER)
86
BYPASS SWITCH
82
A
AMMETER
POWER INDICATOR
84
16
TEST LOAD OUTLET
80
GROUND
SELECTOR SWITCH
AFD = UP POSITION
STANDARD = DOWN POSITION
70
STANDARD BREAKER
ARCING FAULT DETECTION LINE INTERRUPTER
22
10
16
LINE
LINE NEUTRAL
18
14
POWER SOURCE
60

FIG. 7

ARCING FAULT DETECTOR TESTING AND DEMONSTRATION SYSTEM

FIELD OF THE INVENTION

The present invention relates generally to devices which detect hazardous arcing fault conditions in electric circuits and, more particularly, to a device for testing and/or demonstrating an arcing fault detector in relation to a standard circuit breaker.

BACKGROUND OF THE INVENTION

Electrical systems in residential, commercial and industrial applications usually include a panelboard for receiving electrical power from a utility source. To reduce the risk of injury or fire, the power is generally routed through overcurrent protection devices to designated branch circuits supplying one or more loads. The overcurrent protection devices are typically circuit interrupters such as circuit breakers and fuses which are designed to interrupt the electrical current supplied to the loads if the limits of the conductors are surpassed.

Circuit breakers are a preferred type of circuit interrupter because a resetting mechanism allows their reuse. Typically, circuit breakers interrupt an electric circuit due to a disconnect or trip condition such as a current overload or ground fault. The current overload condition results when a current exceeds the continuous rating of the breaker for a time interval determined by the trip current. The ground fault trip condition is created by an imbalance of currents flowing between a line conductor and a neutral conductor such as a grounded conductor, a person causing a current path to ground, or an arcing fault to ground.

However, arcing faults are often undetected by standard circuit breakers. An arcing fault is defined as current through ionized gas between two ends of a broken conductor, between two conductors supplying a load, or between a conductor and ground. Upon occurrence of an arcing fault, branch or load impedance may cause the current levels to be reduced to a level below the trip curve settings of the circuit breaker, causing the arcing fault condition to be undetected by the circuit breaker. In addition, an arcing fault which does not contact a grounded conductor or person will not trip a ground fault protected circuit.

There are many conditions that may cause an arcing fault. For example, corroded, worn or aged wiring or insulation, loose connections, wiring damaged by nails or staples through the insulation, and electrical stress caused by repeated overloading, lightning strikes, etc. These faults may damage the conductor insulation and reach an unacceptable temperature. Arcing faults can cause fire if combustible materials are in close proximity.

There are also many conditions that may cause a "false" arcing fault. For example, the occurrence of an arcing fault in one branch circuit of an electrical distribution system may cause a false arcing fault signal in another branch circuit as a series path is created between the branch circuits through a load center. As a result, circuit interrupters in more than one branch circuit may be erroneously tripped. Another condition that may cause a false arcing fault is a "noisy" load such as an arc welder, electric drill, etc. producing a high frequency disturbance in the electrical circuit which appears to be an arcing fault.

There are several devices in the prior art designed to detect hazardous arcing faults. In addition to detecting arcing faults which otherwise would have been ignored by conventional circuit breakers, the arcing fault detector should preferably be capable of distinguishing arcing faults from high frequency disturbances caused by normal operation of noisy loads, and further should be capable of isolating an arcing fault signal to the particular branch circuit in which the arcing fault occurred, thus preventing "false" arcing fault indications in other branch circuits.

In order to teach the dangers of arcing faults and the associated benefits provided by arcing fault detectors, there is a need for a system to facilitate demonstration and testing of the arcing fault detector in relation to that of a standard circuit breaker. The present invention is directed to providing such a system. It is capable of producing an arcing current between two electrodes connected to a line conductor, demonstrating that a standard circuit breaker does not trip in response to the presence of the arcing condition, and demonstrating that the arcing fault detector trips in response to the same arcing condition. The apparatus is capable of being enclosed within a portable box to facilitate demonstration in a conference room, classroom or other similar environment.

SUMMARY OF THE INVENTION

In accordance with one aspect of the present invention, there is provided a system for demonstrating or testing the operation of an arcing fault detector comprising an electrical circuit including line and neutral conductors connected between a power source and a load, the line conductor carrying an electrical signal between the power source and the load. A selector switch is positioned between the power source and the load and movable between a first position and a second position. An arcing fault detector and associated line interrupter is connected to the line conductor between the power source and the selector switch. A standard circuit breaker is connected in parallel to the arcing fault detector. When the selector switch is in the first position, the electrical signal is provided to the arcing fault detector rather than the standard circuit breaker. When the selector switch is in the second position, the electrical signal is provided to the standard circuit breaker rather than the arcing fault detector. A pair of electrodes is positioned between the selector switch and the load for producing an arcing condition on the line conductor.

In accordance with another aspect of the present invention, there is provided a system for demonstrating or testing the operation of an arcing fault detector comprising an electrical circuit including line and neutral conductors connected between a power source and a load, the line conductor carrying an electrical signal between the power source and the load. A pair of electrodes are positioned between the power source and the load for producing an arcing condition on the line conductor. A line interrupter is provided for interrupting the electrical signal between the power source and the load in response to receiving a trip signal. An arcing fault detector and a standard circuit breaker are connected to the line conductor between the power source and the pair of electrodes. The arcing fault detector produces a trip signal upon detection of an arcing fault on the line conductor, while the standard circuit breaker produces a trip signal upon detection of an overcurrent condition on the line conductor. Upon the occurrence of a trip signal, indicator means are provided for indicating whether the trip signal was produced by the arcing fault detector or the standard circuit breaker.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other advantages of the invention will become apparent upon reading the following detailed description and upon reference to the drawings in which:

FIG. **1** is a block diagram of an arcing fault detector system using a type of arcing fault detector which may be used in the demonstrator apparatus embodying the present invention;

FIG. **2** is a schematic diagram of an electrical circuit for implementing the arcing fault detector system illustrated in FIG. **1**;

FIGS. **3***a* through **3***g* are waveforms at various points in the circuit of FIG. **2**;

FIG. **4** is a schematic diagram of an alternate circuit for use in place of the comparator and single-shot pulse generator in the circuit of FIG. **2**;

FIG. **5** is a schematic diagram of an alternative circuit for implementing the fault detection system illustrated in FIG. **1**;

FIG. **6** is a schematic diagram of an arcing fault detector demonstrator apparatus according to the preferred embodiment of the present invention; and

FIG. **7** is a schematic diagram of an arcing fault detector apparatus according to another embodiment of the present invention.

While the invention is susceptible to various modifications and alternative forms, specific embodiments have been shown by way of example in the drawings and will be described in detail herein. However, it should be understood that the invention is not intended to be limited to the particular forms disclosed. Rather, the invention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the invention as defined by the appended claims.

DESCRIPTION OF SPECIFIC EMBODIMENTS

Turning now to the drawings and referring initially to FIG. **1**, arcing fault detectors **10***a*, **10***b* . . . **10***n* are connected to n branches of an electrical distribution system **12** having a utility company power transformer **14** as a source of electric power. The electrical distribution system **12** includes line conductors **16***a*, **16***b* . . . **16***n* and neutral conductors **18***a*, **18***b* . . . **18***n* which distribute electrical power to loads **20***a*, **20***b* . . . **20***n* through corresponding sensors **21***a*, **21***b* . . . **21***n*, line interrupters **22***a*, **22***b* . . . **22***n*, and blocking filters **23***a*, **23***b* . . . **23***n*. The line conductors **16** and a neutral conductors **18** are typically at 240 volts or 120 volts, and a frequency of 60 Hz.

Each of the line interrupters **22** is preferably a circuit breaker which includes an overload trip mechanism having a thermal/magnetic characteristic which trips the breaker contacts to an open circuit condition in response to a given overload condition, to disconnect the corresponding load **20** from the power source, as is known in the art. It is also known to provide the circuit breaker **22** with ground fault interrupter circuitry responding to a line or neutral-to-ground fault to energize a trip solenoid which trips the circuit breaker and opens the contacts.

The sensors **21** monitor the rate of change of electrical current in the respective line conductors **16** and produce signals representing the rate of change. The rate-of-change signal from each sensor **21** is supplied to the corresponding arc detector **10**, which produces a pulse each time the rate-of-change signal increases above a selected threshold. The rate-of-change signal and/or the pulses produced therefrom are filtered to eliminate signals or pulses outside a selected frequency range. The final pulses are then monitored to detect when the number of pulses that occur within a selected time interval exceeds a predetermined threshold. In the event that the threshold is exceeded, the detector **10** generates an arc-fault-detection signal that can be used to trip the corresponding line interrupter **22**.

The pattern of fluctuations in the rate-of-change signal produced by the sensor **21** indicates whether the condition of the circuit is a normal load, a normal switching event, a phase-controlled fired load, or an arcing fault event. One example of a suitable sensor for producing the desired rate-of-change signal is a toroidal sensor having an annular core encompassing the current-carrying load line, with the sensing coil wound helically on the core. The core is made of magnetic material such as a ferrite, iron, or molded permeable powder capable of responding to rapid changes in flux. A preferred sensor uses a ferrite core wound with 200 turns of 24–36 gauge copper wire to form the sensing coil. An air gap may be cut into the core to reduce the permeability to about 30. The core material preferably does not saturate during the relatively high currents produced by parallel arcs, so that arc detection is still possible at those high current levels.

Other means for sensing the rate of change of the current in a line conductor are contemplated by the present invention. By Faraday's Law, any coil produces a voltage proportional to the rate of change in magnetic flux passing through the coil. The current associated with an arcing fault generates a magnetic flux around the conductor, and the coil of the sensor **21** intersects this flux to produce a signal. Other suitable sensors include a toroidal transformer with a core of magnetic material or an air core, an inductor or a transformer with a laminated core of magnetic material, and inductors mounted on printed circuit boards. Various configurations for the sensor core are contemplated by the present invention and include toroids which have air gaps in their bodies.

Preferably, the rate-of-change signal produced by the sensor **21** represents only fluctuations in the rate of change within a selected frequency band. The sensor bandpass characteristic is preferably such that the lower frequency cut-off point rejects the power frequency signals, while the upper frequency cut-off point rejects the high frequency signals generated by noisy loads such as a solder gun, electric saw, electric drill, or like appliances, equipment, or tools. The resulting output of the sensor **21** is thus limited to the selected frequency band associated with arcing faults, thereby eliminating or reducing spurious fluctuations in the rate-of-change signal which could result in nuisance tripping. As an example, the sensor bandpass characteristic may have: (1) a lower frequency cut-off point or lower limit of 60 Hz so as to reject power frequency signals, and (2) an upper frequency cut-off point or upper limit of approximately 1 MHz so as to effectively reject high frequency signals associated with noisy loads. These specific frequency cut-off points for the sensor bandpass characteristic are by way of example only, and other appropriate frequency cut-off limits may be adopted depending upon actual frequency ranges for the power signals as well as the noisy load signals.

The desired bandpass characteristic is realized by appropriately selecting and adjusting the self-resonant frequency of the sensor. The current-type sensor is selected to have a predetermined self-resonant frequency which defines associated upper and lower frequency cut-off or roll-off points for the operational characteristics of the sensor. Preferably, the current-type sensor is designed to exhibit the desired bandpass filtering characteristic as it operates to detect the rate of change of current variations within the load line being monitored. The present invention contemplates other means for bandpass filtering the signal output within the selected frequency band. For example, a bandpass filter or a combination of filters in a circuit can be used to attenuate frequencies above or below the cut-off points for the selected frequency band.

FIG. 2 illustrates a preferred circuit for one of the arc detectors **10**. The sensor **21** produces the desired rate-of-change signal (commonly referred to as a "di/dt signal") in the form of an output voltage which is connected to a comparator circuit **30** through a filtering network in the sensor and a diode D3. The rate-of-change signal originates in the sensor coil T1 which is wound on a core surrounding the load line **16**. Connected in parallel with the sensor coil T1 are a pair of diodes D1 and D2 which serve as clamping devices during high-power transient conditions. A resistor R1 in parallel with the diodes D1 and D2 dampens self-ringing of the sensor, during high-power transients. A pair of capacitors C1 and C2 in parallel with the resistor R1, and a resistor R2 and an inductor L1 connected in series to the input to the comparator **30**, are tuned to assist in attaining the desired rolloff characteristics of the filtering network formed thereby. For example, with the illustrative values listed below for the components of the circuit of FIG. **2**, the sensor has a passband extending from about 10 KHz to about 100 KHz, with sharp rolloff at both sides of the passband.

The operation of the circuit of FIG. **2** can be more clearly understood by reference to the series of waveforms in FIGS. **3***a* through **3***g*. FIG. **3***a* is an actual waveform from an oscilloscope connected to a line conductor **16** carrying a-c. power at 60 Hz and experiencing a high-frequency disturbance beginning at time t**1**. Because the high-frequency disturbance is within the frequency range to which the sensor **21** is sensitive (e.g., from about 10 KHz to about 100 KHz), the disturbance results in a burst of high-frequency noise in the di/dt output signal (FIG. **3***b*) from the sensor **21** (at point A in the circuit of FIG. **2**), beginning at time t**1**. The noise burst has a relatively high amplitude from time t**1** until approximately time t**2**, and then continues at a low amplitude from time t**2** to about time t**3**.

In the comparator **30**, the magnitude of the rate-of-change signal from the sensor **21** is compared with the magnitude of a fixed reference signal, and the comparator **30** produces an output voltage only when the magnitude of the rate-of-change signal crosses that of the reference signal. This causes the detector **10** to ignore low-level signals generated by the sensor **21**. All signals having a magnitude above the threshold level set by the magnitude of the reference signal are amplified to a preset maximum value to reduce the effect of a large signal. In the comparator **30**, a transistor Q1 is normally turned on with its base pulled high by a resistor R3. A diode D3 changes the threshold and allows only the negative pulses from the sensor **21** to be delivered to the base of transistor Q1. When the signal to the comparator drops below the threshold level (minus 0.2 volt for the circuit values listed below), this causes the transistor Q1 to turn off. This causes the collector of the transistor Q1 to rise to a predetermined voltage, determined by the supply voltage V_{cc}, a resistor R4 and the input impedence of a single-shot pulse generator circuit **40**. This collector voltage is the output of the comparator circuit **30**. The collector voltage remains high as long as the transistor Q1 is turned off, which continues until the signal from the sensor **21** rises above the threshold level again. The transistor Q1 then turns on again, causing the collector voltage to drop. The end result is a pulse output from the comparator, with the width of the pulse corresponding to the time interval during which the transistor Q1 is turned off, which in turn corresponds to the time interval during which the negative-going signal from the sensor **21** remains below the threshold level of the comparator.

The arcing fault detection system **10** can also include a filter **40** for blocking false arcing fault signals or other nuisance output signals generated by normal operation of the load **20**. The blocking filter **40** is connected between the sensor **30** and the load **20** on each branch circuit to prevent the false arcing fault signals from being delivered to the sensor **30**. As seen in FIG. **1**, capacitors **42** connect the load line **24** to the neutral line **26** on each branch circuit. An inductor **44** is connected to the load line **24** between the connections of the two capacitors **42** to the load line **24**.

The noise burst in the sensor output is filtered to produce the waveform shown in FIG. **3***c* at point B in the circuit of FIG. **2**. The waveform at point C in the circuit of FIG. **2** is shown in FIG. **3***d,* and it can be seen that the amplitude has been reduced and a d-c. offset has been introduced by summing the filtered di/dt signal with a d-c. bias from the supply voltage V_{cc} at point C. This is the input signal to the base of the transistor Q1.

The output of the transistor Q1 is a series of positive-going pulses corresponding to the negative-going peaks in the input signal. The transistor output, at point D in the circuit of FIG. **2**, is shown in FIG. **3***e*. It can be seen that the transistor circuit functions as a comparator by producing output pulses corresponding only to negative-going peaks that exceed a certain threshold in the filtered di/dt signal shown in FIG. **3***c*. At this point in the circuit, the pulses vary in both width and amplitude, as can be seen in FIG. **3***e*.

To convert the output pulses of the comparator **30**, which vary in both width and amplitude, into a series of pulses of substantially constant width and amplitude, the comparator output is fed to a single-shot pulse generator circuit **40**. This high-pass filter circuit includes a pair of capacitors C3 and C4 connected in series to the collector of the transistor Q1, and two resistor-diode pairs connected in parallel from opposite sides of the capacitor C4 to ground. The pulses produced by this circuit will be described in more detail below in connection with the waveforms shown in FIG. **3**. The output pulses are predominantly pulses of equal width and amplitude, although occasional larger or smaller pulses can result from especially large or small input pulses.

The variable-width and variable-amplitude pulses of FIG. **3***e* are converted to a series of pulses of substantially constant width and amplitude by the single-shot pulse generator circuit **40**. The output of this circuit **40**, at point E in the circuit of FIG. **2**, is shown in FIG. **3***f*. Although all the pulses shown in FIG. **3***f* are of substantially the same size, larger or smaller pulses may be produced by di/dt spikes that are excessively large or excessively small. The vast majority of the pulses at point E, however, are substantially independent of the amplitude and duration of the corresponding spikes in the di/dt signal, provided the spikes are large enough to produce an output pulse from the comparator **30**.

The substantially uniform pulses produced by the circuit **40** are supplied to the base of a transistor Q2 through a current-limiting resistor R7. A capacitor C5 connected from the transistor base to ground improves the sharpness of the roll-off of the bandpass filtering. The transistor Q2 is the beginning of an integrator circuit **50** that integrates the pulses produced by the circuit **40**. The pulses turn the transistor on and off to charge and discharge a capacitor C6 connected between the transistor emitter and ground. A resistor R9 is connected in parallel with the capacitor C6, and a resistor R8 connected between the supply voltage and the collector of the transistor Q2 determines the level of the charging current for the capacitor C6. The magnitude of the charge on the capacitor C6 at any given instant represents the integral of the pulses received over a selected time interval. Because the pulses are substantially uniform in width and amplitude, the magnitude of the integral at any given instant is primarily a function of the number of pulses received within the selected time interval immediately preceding that instant. Consequently, the value of the integral can be used to determine whether an arcing fault has occurred.

The integral signal produced by the circuit **50** is shown in FIG. **3***g*, taken at point F in the circuit of FIG. **2**. It can be seen that the integrator circuit charges each time it receives a pulse from the circuit **40**, and then immediately begins to discharge. The charge accumulates only when the pulses appear at a rate sufficiently high that the charge produced by one pulse is less than the discharge that occurs before the next pulse arrives. If the pulses arrive in sufficient number and at a sufficient rate to increase the integral signal to a trip threshold level TR (FIG. **3***g*), SCR**1** is triggered to trip the circuit breaker. The circuit is designed so that this occurs only response to a di/dt signal representing an arcing fault.

When SCR**1** is turned on, a trip solenoid S**1** is energized to disconnect the load from the circuit in the usual manner. Specifically, turning on SCR**1** causes current to flow from line to neutral through a diode bridge formed by diodes D**7**–D**10**, thereby energizing the solenoid to open the circuit breaker contacts in the line **16** and thereby disconnect the protected portion of the system from the power source. The d-c. terminals of the diode bridge are connected across SCR**1**, and the voltage level is set by a zener diode D**6** in series with a current-limiting resistor R**10**. A varistor V**1** is connected across the diode bridge as a transient suppressor. A filtering capacitor C**7** is connected across the zener diode D**6**. The trip circuit loses power when the circuit breaker contacts are opened, but of course the contacts remain open until reset.

One example of a circuit that produces the desired result described above is the circuit of FIG. **2** having the following values:

D**1**
1N4148
D**2**
1N4148
D**3**
1N4148
D**4**
1N4148
D**5**
1N4148
D**6**
27 v zener
R**1**
3.01K
R**2**
1.3K
R**3**
174K
R**4**
27.4K
R**5**
10K
R**6**
10K
R**7**
10K
R**8**
4.2K
R**9**
4.75K
R**10**
24K
L**1**
3300 uH
L**2**
500 uH
L**3**
500 uH
C**1**
0.012 uF
C**2**
0.001 uF
C**3**
0.001 uF
C**4**
0.001 uF
C**5**
0.001 uF
C**6**
6.8 uF
C**7**
1.0 uF
C**8**
1.0 uF
Q**1**
2N2222 A
Q**2**
2N2222 A
SCR**1**
CR08AS-12 made by POWEREX-Equal
V_{cc}
27 v

Although a circuit breaker is the most commonly used line interrupter, the output device may be a comparator, SCR, relay, solenoid, circuit monitor, computer interface, lamp, audible alarm, etc.

It will be understood that a number of modifications may be made in the circuit of FIG. **2**. For example, the discrete bandpass filter between the sensor and the comparator can be replaced with an active filter using an operational amplifier. As another example, a single-shot timer can be used in place of the single-shot pulse generator in the circuit of FIG. **2**. This circuit can receive the output signal from an active filter as the trigger input to an integrated-circuit timer, with the output of the timer supplied through a resistor to the same integrator circuit formed by the resistor R**9** and capacitor C**6** in the circuit of FIG. **2**.

FIG. **4** illustrates a frequency-to-voltage converter circuit that can be used in place of all the circuitry between point A and the integrator circuit in FIG. **2**. In this circuit, the signal from point A in FIG. **2** is supplied through a resistor Ra to a frequency/voltage converter integrated circuit **55** such as an AD537 made by Analog Devices Inc. The output of the integrated circuit **55** is fed to a pair of comparators **56** and **57** that form a conventional window comparator. Specifically, the output of the circuit **55** is applied to the inverting input of a comparator **56** and to the non-inverting input of a comparator **57**. The other inputs of the comparators **56** and **57** receive two different reference signals A and B which set the limits of the window, i.e., the only signals that pass through the window comparator are those that are less than reference A and greater than reference B.

FIG. **5** illustrates an arc detector **10** for sensing the rate of change of the line voltage, i.e., dv/dt, rather than current. The sensor in this circuit is a capacitor C**10** connected between a line conductor **16** and an inductor L**10** leading to ground. The inductor L**10** forms part of a bandpass filter that passes only those signals falling within the desired frequency band, e.g., between 10 KHz and 100 KHz. The filter network also includes a resistor R**10**, a capacitor C**11** and a second inductor L**11** in parallel with the first inductor L**10**, and a resistor R**11** connected between the resistor R**10** and the capacitor C**11**. The resistor R**10** dampens the ringing between the capacitor C**10** and the inductor L**10**, and the resistor R**11** adjusts the threshold or sensitivity of the circuit. The inductors L**10** and L**11** provide low-frequency roll-off at the upper end of the pass band, and a capacitor C**11** provides the high-frequency roll-off at the lower end of the pass band.

The capacitor C**10** may be constructed by attaching a dielectric to the line bus so that the bus forms one plate of the capacitor. The second plate of the capacitor is attached on the opposite side of the dielectric from the bus. The sensor circuit is connected to the second plate.

The output of the bandpass filter described above is supplied to a comparator **60** to eliminate signals below a selected threshold, and to limit large signals to a preselected maximum amplitude. The filter output is applied to the inverting input of the comparator **60**, through the resistor R**11**, while the non-inverting input receives a reference signal set by a voltage divider formed by a pair of resistors R**12** and R**13** connected between V_{cc} and ground. The comparator **60** eliminates very low levels of signal received from the sensor. The comparator **60** is normally off when there is no arcing on the line conductor **16**, and thus the comparator output is low. When the voltage signal from the sensor is more negative than the reference input (e.g., −0.2 volts), the output from the comparator goes high, and a forward bias is applied to the transistor Q**2** that drives the integrator circuit. A capacitor C**12** connected from the base of transistor Q**2** to $-V_{cc}$ filters out high frequency noise. A diode D**11** is connected between the comparator output and the base of the transistor Q**2** to block negative signals that would discharge the capacitor C**12** prematurely. The rest of the circuit of FIG. **5** is identical to that of FIG. **2**.

When a fault occurs, it is desirable to isolate the branch of the distribution system in which the arcing fault occurred, from the rest of the distribution system. In the system of FIG. **1**, using the current-type sensor, such isolation is provided by a capacitor C**8** connected between the load line **16** and the neutral line **18** in each branch of the distribution system. The capacitor C**8** is located between the line interrupter **22** and the power source **14** to provide a low impedance path for an arcing fault from the load line **16** to the neutral line **18**, independent of the impedance of the load **20**. The capacitor C**8** thus prevents a series path from being created between branch circuits, even though the power transformer **14** appears as a high impedance to the high frequency current that an arcing fault generates.

The isolating capacitor C**8** allows the sensor **21** to be sensitive even when all the loads are off-line and the impedance is high. As the loads come on-line, the impedance decreases. Without the isolating capacitor C**8**, a series path could be created between branch circuits. For example, current flow along the neutral line of a first branch circuit, within which an arcing fault is generated, could travel along the load line of the first branch circuit. The current could then continue through the load line of second branch circuit, subsequently flowing along the neutral line of the second branch circuit. The isolating capacitor C**8** prevents this pathway between branch circuits from being formed.

With the voltage-type sensor shown in FIG. **5**, isolation is provided by an inductor L**2** in the load line **16** for each branch circuit. Each inductor L**2** is located between the line interrupter **22** and the sensor **21** to provide an impedance for the current produced by an arcing fault.

The isolating capacitors C**8** and the isolating inductors L**2** may be used simultaneously in their respective positions in the branch circuits. This combination can be particularly useful if the sensors monitor both the current and voltage changes in the branch circuits to detect arcing faults.

The arcing fault detection system also includes a blocking filter **23** in each branch circuit for blocking false arcing fault signals or other nuisance output signals generated by normal operation of the load **20**. Each blocking filter **23** is connected between the sensor **21** and the load **20** in each branch circuit to prevent false arcing fault signals from being delivered to the sensor **21**. As seen in FIGS. **2** and **5**, the preferred blocking filter includes a pair of capacitors C**9***a* and C**9***b* connected between the load line **16** and the neutral line **18** of each branch circuit. An inductor L**3** is connected in the load line **16** between the two capacitors C**9***a* and C**9***b*. Preferably, the capacitors C**9***a* and C**9***b* have a rating across the line of about 0.47 uF. The inductor L**3** has a rating for 15 amps at 500 uH and dimensions of about 1.5" diameter and 1.313" in length (e.g., Dale IHV 15–500). These values, of course, can be adjusted for the power rating of the electrical system and the loads **20**.

The capacitor C**9***a* creates a low impedance path for any series arcing that occurs upstream of that capacitor, such as arcing within the wall upstream of a noisy load. This permits series arcing to be detected in the branch containing the blocking filter. The inductor L**3** creates an impedance that does most of the attenuation of the signal created by a noisy load. This inductor is sized to carry the load current of the device, which is typically 15 or 20 amperes. The second capacitor C**9***b* reduces the amount of inductance required in the inductor L**3**, by creating a low impedance path across the load **20**.

One of the advantages of the blocking filter **23** is that it can be used locally on a particular branch circuit that is known to connect to a load **20** which is noisy. The expense of using the blocking filter **23** is reduced since it can be used only where needed. The blocking filter **23** also allows easy retrofitting to existing electrical distribution systems in residences and commercial space.

Although the above system has been described in connection with an ordinary 120 volt system, it is applicable to the voltages of any standard, including 12, 120, 240, 480, 600 and 18500 volts. The system is suitable for use in residential, commercial and industrial applications, single-shot or multiphase systems and at all frequencies for a-c. as well as d-c. This system is applicable to automotive, aviation, and marine needs, separately derived sources such as generators or UPS, and capacitor banks needing incipient fault protection.

Although the above system has been illustrated with circuit breakers, it can also be used with circuit/load monitoring devices, motor monitoring devices, receptacles, cord plugs, portable diagnostic devices, appliances, switches and fuses.

One of the many application of the above system is its use with ground fault circuit interrupters (GFCI's). An example of a ground fault interrupter is a fast acting circuit breaker that disconnects equipment from the power line when some current returns to the source through a ground path. Under normal circumstances all current is supplied and returned within the power conductors. But if a fault occurs and leaks some current to ground, the GFCI senses the difference in current in the power conductors. If the fault level exceeds the trip level of the GFCI, which is usually at about 6 mA, the GFCI disconnects the circuit.

Three types of GFCI are commonly available. The first or separately enclosed type is available for 120-volt, 2-wire and 12/240-volt, 3-wire circuits up to 30 amp. The second type combines a 15-, 20-, 25-, or 30-amp circuit breaker and a GFCI in the same plastic case. It is installed in place of an ordinary breaker in a panelboard and is usually available in 120-volt, 2-wire, or 120/240-volt, 3-wire types which may also be used to protect a 240-volt, 2-wire circuit. The second type provides protection against ground faults and overloads for all outlets on the circuit. A third type having a receptacle and a GFCI in the same housing provides only ground-fault protection to the equipment plugged into that receptacle. There are feed-through types of GFCI which provide protection to equipment plugged into other ordinary receptacles installed downstream on the same circuit.

Ground fault equipment is commercially available from the Square D Company under the catalog designations GROUND CENSOR™, HOMELINE®, QO®, TRILLIANT® and MICROLOGIC® ground fault modules. This ground fault equipment is suitable for protection of main, feeder, and motor circuits on electrical distribution systems. It is also usable as ground fault relay and ground fault sensing devices. The arc detection systems described above can be advantageously used to supplement the circuit protection provided by all the foregoing types of GFCIs.

The term arcing fault, as used herein, includes faults caused by either series arcs (both line and neutral) or parallel arcs (line to line, line to ground, or line to neutral). The term arc, as used herein, includes not only a discharge of electricity through a gas or across an insulating medium, but also high impedance faults or other intended or unintended circuit paths which do not have sufficient energy or current flow to trip a breaker, but nevertheless can generate damaging heat or other undesirable effects.

The term mutual inductance, as used herein, is the property shared by neighboring inductors or inductive devices which enables electromagnetic induction to take place. The term rate of current or voltage change, as used herein, measures the change the current or voltage over the period in time corresponding to the measurement. The current generates a flux around the conductor which rapidly changes with the fluctuations in current.

Referring now to FIG. 6, there is provided a schematic diagram of an arcing fault detector testing and demonstration system generally designated by reference numeral **60**. The demonstration system **60** is preferably enclosed within a portable housing (not shown) so that it may be easily transported to various demonstration or testing sites. The housing may be varied in size or eliminated altogether to suit the individual needs of a user. The testing and demonstration system **60** comprises an electrical circuit including a line conductor **16** and a neutral conductor **18** connecting a power source **14** to a load.

Power is supplied to the testing and demonstration system **60** by connecting the line conductor **16** to an external power source **14** by means of a standard electrical outlet or any other suitable means known in the art. A test load (not shown) is connected to the testing and demonstration system by plugging into a test load outlet **80**. In the embodiment shown in FIG. **6**, the test load outlet **80** comprises a standard electrical outlet, but it will be appreciated that the test load may be connected to the testing and demonstration system by any other suitable means known in the art. The test load outlet **80** enables the operator to plug in a variety of different loads in order to operate the testing and demonstration system **60** in response to a variety of different loads, including "noisy" loads which may produce high frequency disturbances on the line conductor **16**.

A selector switch **74** is movable between an "AFD" (arcing fault detector) position and a "STANDARD" position in order to selectively connect the power source **14** to the test load between two alternate electrical paths. The selector switch **74** may be any of several devices known in the art including, for example, a physical switch movable by an operator or an electrically controllable switching device. When the selector switch **74** is in the "AFD" position, the current flowing through the line conductor **16** is routed to an arcing fault detector **10**, which produces an arcing fault detection signal and triggers the line interrupter **22** to an open-circuit condition if an arcing fault condition has occurred. Preferably, the arcing fault detector **10** will be the system described in relation to FIGS. **1–5**, but it will be appreciated that other types of arcing fault detectors may be used. When the selector switch **74** is in the "STANDARD" position, the current flowing through the line conductor **16** is routed to a standard circuit breaker **70**, which will trip open if the current flowing through the line conductor **16** exceeds the trip curve settings of the circuit breaker. However, the standard circuit breaker **70** typically will not trip open in response to an arcing fault, because the current levels typically are below the trip curve settings of the circuit breaker.

Alternatively, as shown in FIG. **7**, the arcing fault detector **10** and standard circuit breaker **70** may be connected in series rather than in parallel. In such a case, the selector switch may be eliminated, causing the current flowing through the line conductor **16** to be routed across both the arcing fault detector **10** and standard circuit breaker **70**. Additionally, a single line interrupter may be employed rather than both the arc fault detector **10** and the standard circuit breaker having their own associated line interrupter. The arcing fault detector **10** will produce an arcing fault detection signal and trigger the line interrupter **22** to an open circuit condition in response to an arcing fault, while the standard circuit breaker **70** will trigger open the line interrupter in response to a current overload or ground fault condition. In this configuration, however, in the event the circuit is tripped open, some type of external indicator (not shown) must be provided in order to reveal whether the trip signal was produced by the arcing fault detector **10** or by the standard circuit breaker **70**.

The testing and demonstration system **60** further includes a first electrode **62** and a second electrode **64** connected to the line conductor **16** between the test load outlet **80** and the selector switch **74**. The first and second electrodes **62**, **64** are movable between an initial contact position and a separated position in order to receive a load current and produce a "series" arcing condition between them. In the embodiment shown in FIG. **6**, the first electrode **62** is stationary while the second electrode **64** is movable away from the first electrode until the electrodes are separated by the distance needed to produce the desired arcing condition. Alternatively, the first electrode **62** may be movable and the second electrode **64** stationary, or both electrodes **62**, **64** may be movable, as long as the electrodes are movable relative to each other. The electrodes **62**, **64** may be movable by means of a micrometer **66**, as shown in FIG. **6**, or by any other suitable means known in the art for linearly positioning the electrodes **62**, **64** relative to each other. In either case, whether using a micrometer **66** or an alternative linear positioning device, the act of adjusting the relative position of the electrodes may be accomplished by a user manually adjusting the positioning device, or by the positioning device being remotely controlled by a computer or other suitable control system. In an embodiment in which the linear positioning device is controlled by a computer, the computer may be programmed to move the positioning device in a precise incremental step pattern or at a predetermined rate. The same computer program may thereafter be used in repeated tests or demonstrations of the system **60** if it is desired to accurately repeat the same pattern of movement of the electrodes **62**, **64**.

In a preferred embodiment, one of the two electrodes **62**, **64** is made of copper and the other of the two electrodes **62**, **64** is made of carbon, in order to simulate corroded, worn or aged wiring or insulation which has become "carbonized" and is capable of sustaining a dangerous arcing fault condition. Upon receiving the load current, a high temperature is produced and sustained across the interface between the two electrodes **62** and **64**, ionizing the gas between them and creating an arcing fault condition. As will be appreciated by those skilled in the art, arcing fault conditions may also be produced at the interface between electrodes made of alternate materials, but it has been found that a carbon-copper electrode interface is ideal for producing arcing fault conditions.

In the embodiment shown in FIG. **6**, the testing and demonstration system **60** further includes an ammeter **82** between the test load outlet **80** and the electrodes **62**, **64** for monitoring the level of current provided to the electrodes **62**, **64**. A bypass switch **86** is connected in parallel to the electrodes **62**, **64** to enable a user to bypass the electrodes **62**, **64** when the bypass switch **86** is in a closed position. The testing and demonstration system **60** further includes an indicator light **84** for indicating when power is being supplied to the system **60** and for indicating when the line interrupter **22** has been tripped open in response to the detection of an arcing fault, current overload or ground fault condition. When power is being supplied to the system **60**, the indicator light **84** is illuminated. Thereafter, upon the line interrupter **22** being tripped open in response to a fault condition, the indicator light **84** becomes de-illuminated, indicating that power is no longer being supplied to the load. As will be appreciated by those skilled in the art, however, other types of indicator devices may be used in place of or in addition to an indicator light. As an additional safety measure, a welding screen (not shown) may be provided to shield the user from direct observation of an arcing condition.

One preferred method of demonstrating the system **60** is described as follows. With the selector switch **74** in the "STANDARD" position, the operator first plugs a test load such as a hair dryer into the test outlet **80**. The operator then adjusts the electrodes **62**, **64** so that they are touching each other, turns on the hair dryer and observes the ammeter **82** to determine the level of load current flowing through the electrodes. Next, the operator slowly separates the electrodes **62**, **64** by rotating the micrometer **66** until arcing is produced across the electrodes, using the ammeter **82** to show that the load current decreases only slightly when arcing is produced, and using the standard circuit breaker **70** to show that it does not detect the arcing fault condition. A combustible material such as wood or plastic may then be placed near the electrodes to show that a fire is easily created by the arcing fault condition. In the next phase of the demonstration, after the electrodes **62**, **64** have been readjusted to their initial positions, the operator moves the selector switch **74** to the "AFD" position, plugs a test load into the test outlet **80**, and again slowly separates the electrodes **62**, **64** until arcing is produced. In this phase, however, it can be observed that the arcing fault detector **10** is able to detect the arcing fault condition and trip open the circuit after only a short flash is produced between the electrodes which is generally insufficient to start a fire, thus indicating that arcing fault detectors provide a significant degree of fire protection not provided by standard circuit breakers.

Alternatively, the system **60** may be operated as follows. With the selector switch **74** in the "STANDARD" position, the operator plugs a test load into the test outlet **80** and adjusts the electrodes **62**, **64** until arcing is produced across the electrodes in the manner described above. Then, while the arcing fault condition is occurring and after observing that the standard circuit breaker **70** does not detect the arcing fault condition, the operator moves the selector switch **74** to the "AFD" position to show that the arcing fault detector **10** is able to detect the arcing fault condition and trip open the circuit.

While the present invention has been described with reference to one or more particular embodiments, those skilled in the art will recognize that many changes may be made thereto without departing from the spirit and scope of the present invention. Such variations are contemplated as falling within the spirit and scope of the claimed invention, as set forth in the following claims.

We claim:

1. A system for demonstrating or testing the operation of an arcing fault detector in comparison to a standard circuit breaker, the system comprising:

- a power circuit including a power source, a load, and a standard circuit breaker;
- an arcing fault detector and associated line interrupter in parallel with said standard circuit breaker;
- pair of electrodes connected in series with said load for producing an arcing condition; and
- a selector switch for selectively connecting said pair of electrodes to one of said standard circuit breaker and said arcing fault detector and associated line interrupter.

2. The system of claim **1** wherein the standard circuit breaker, the arcing fault detector and the pair of electrodes are physically remote from an electrical distribution panelboard so that demonstration and testing of the arcing fault detector in comparison to the circuit breaker may be accomplished remote from the panelboard.

3. The demonstration and testing system of claim **2** further comprising an ammeter connected between said load and said pair of electrodes for monitoring levels of load current supplied to said pair of electrodes.

4. The demonstration and testing system of claim **3** further comprising an indicator device for indicating when power is being supplied to said demonstration and testing system.

5. The demonstration and testing system of claim **4** wherein the indicator device further indicates when power to said demonstration and testing system has been interrupted by said line interrupter.

6. The demonstration and testing system of claim **2** wherein one of said pair of electrodes is comprised of copper and another one of said pair of electrodes is comprised of carbon.

7. The demonstration and testing system of claim **6** wherein a first one of said pair of electrodes is in a stationary position and a second one of said pair of electrodes is movable to a variable position relative to the first electrode.

8. The demonstration and testing system of claim **6** further comprising a linear positioning device for positioning the second electrode relative to the position of the first electrode.

9. The demonstration and testing system of claim **8** wherein the standard circuit breaker, arcing fault detector, pair of electrodes and selector switch are enclosable within a portable case.

10. A method of demonstrating or testing the operation of an arcing fault detector in comparison to a standard circuit breaker, said method comprising the steps of:

supplying a load current to a pair of electrodes;

producing a simulated arcing fault condition between said pair of electrodes;

selectively connecting said pair of electrodes to an arcing fault detector and to a standard circuit breaker;

observing that the standard circuit breaker does not trip in response to the simulated arcing fault condition; and

observing that the arcing fault detector trips in response to the simulated arcing fault condition.

11. A system for demonstrating or testing the operation of an arcing fault detector in comparison to a standard circuit breaker, the system comprising:

an electrical circuit including line and neutral conductors connected between a power source and a load, said line conductor carrying an electrical signal between said power source and said load;

a selector switch positioned between the power source and the load and movable between a first position and a second position;

an arcing fault detector and associated line interrupter connected to said line conductor between said power source and said selector switch, said electrical signal being provided to said arcing fault detector in response to said selector switch being in said first position, said electrical signal not being provided to said arcing fault detector in response to said selector switch being in said second position;

a standard circuit breaker in parallel to said arcing fault detector and connected to said line conductor between said power source and said selector switch, said electrical signal being provided to said standard circuit breaker in response to said selector switch being in said second position, said electrical signal not being provided to said standard circuit breaker in response to said selector switch being in said first position; and

a pair of electrodes positioned between said selector switch and said load for producing an arcing condition on said line conductor.

12. The system of claim **11** wherein the standard circuit breaker, the arcing fault detector and the pair of electrodes are physically remote from an electrical distribution panelboard so that demonstration and testing of the arcing fault detector in comparison to the circuit breaker may be accomplished remote from the panelboard.

13. The demonstration and testing system of claim **12** wherein a first one of said pair of electrodes is comprised of copper and a second one of said pair of electrodes is comprised of carbon.

14. The demonstration and testing system of claim **12** wherein a first one of said pair of electrodes is in a stationary position and a second one of said pair of electrodes is movable to a variable position relative to the first electrode, said demonstration and testing system including a linear positioning device for positioning the second electrode relative to the position of the first electrode.

15. A system for demonstrating or testing the operation of an arcing fault detector in comparison to a standard circuit breaker, the system comprising:

an electrical circuit including line and neutral conductors connected between a power source and a load, said line conductor carrying an electrical signal between said power source and said load;

a pair of electrodes positioned between said power source and said load for producing an arcing condition on said line conductor;

a line interrupter for interrupting the electrical signal between said power source and said load in response to receiving a trip signal;

an arcing fault detector connected to said line conductor between said power source and said pair of electrodes, said arcing fault detector producing said trip signal upon detection of an arcing fault on said line conductor;

a standard circuit breaker connected in series to said arcing fault detector on said line conductor between said power source and said pair of electrodes, said standard circuit breaker producing said trip signal upon detection of an overcurrent condition on said line conductor; and

indicator means for indicating which one of said arcing fault detector and said standard circuit breaker produced said trip signal in response to said line interrupter interrupting the electrical signal between said power source and said load.

16. The system of claim **15** wherein the standard circuit breaker, the arcing fault detector and the pair of electrodes are physically remote from an electrical distribution panelboard so that demonstration and testing of the arcing fault detector in comparison to the circuit breaker may be accomplished remote from the panelboard.

17. The demonstration and testing system of claim **16** further comprising:

an ammeter connected in series with said load for monitoring levels of load current supplied to said pair of electrodes;

an indicator device for indicating when power is being supplied to said demonstration and testing system; and

a bypass switch movable between an open position and a closed position, said load current being provided to said pair of electrodes in response to said bypass switch being in said open position, said load current bypassing said pair of electrodes in response to said bypass switch being in said closed position.

18. The demonstration and testing system of claim **17** wherein the indicator device further indicates when power to said demonstration and testing system has been interrupted.

19. The demonstration and testing system of claim **16** wherein a first one of said pair of electrodes is comprised of copper and a second one of said pair of electrodes is comprised of carbon.

20. The demonstration and testing system of claim **16** wherein the first electrode is in a stationary position and the second electrode is movable to a variable position relative to the first electrode, said demonstration and testing system including a linear positioning device for measuring the position of the second electrode relative to the position of the first electrode.

21. The method of claim **10** wherein the standard circuit breaker, the arcing fault detector and the pair of electrodes are physically remote from an electrical distribution panelboard so that demonstration and testing of the arcing fault detector in comparison to the circuit breaker may be accomplished remote from the panelboard.

22. The demonstration and testing system of claim **12** further comprising:

an ammeter connected in series with said load for monitoring levels of load current supplied to said pair of electrodes;

an indicator device for indicating when power is being supplied to said demonstration and testing system and for indicating when power to said demonstration and testing system has been interrupted by said line interrupter; and

a bypass switch movable between an open position and a closed position, said load current being provided to said pair of electrodes in response to said bypass switch being in said open position, said load current bypassing said pair of electrodes in response to said bypass switch being in said closed position.

23. The demonstration and testing system of claim **4** further comprising a bypass switch movable between an open position and a closed position, said load current being provided to said pair of electrodes in response to said bypass switch being in said open position, said load current bypassing said pair of electrodes in response to said bypass switch being in said closed position.

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